Simulation and Analysis of Opportunistic MSPA for Multiple Cubesat Deployments

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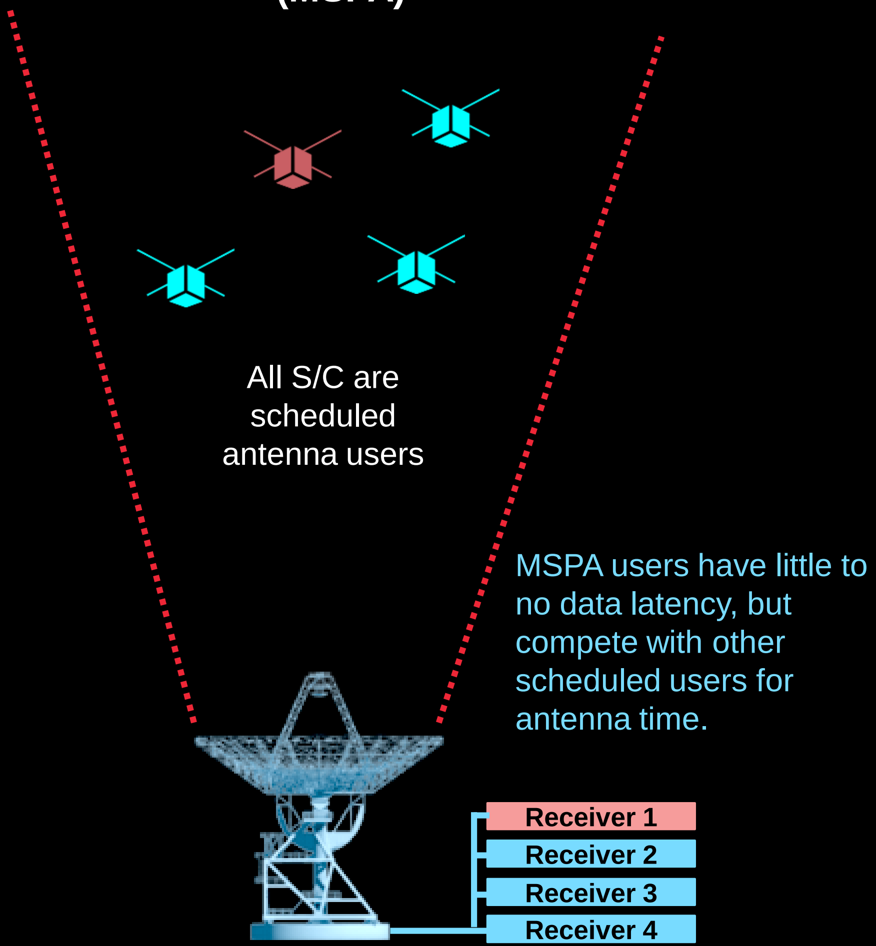
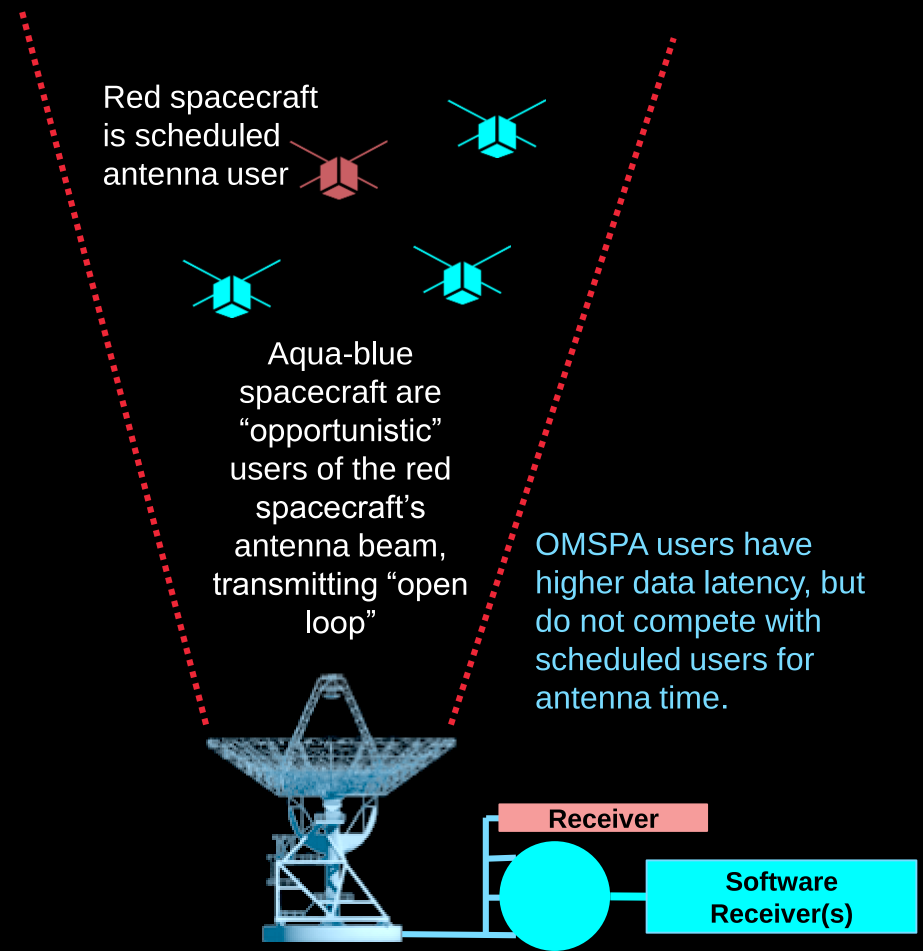
Background: MSPA vs. OMSPA

Multiple Spacecraft Per Antenna (MSPA)



Opportunistic Multiple Spacecraft Per Antenna (OMSPA) Concept



The Value Proposition

Why are MSPA and OMSPA important from the user missions' perspective?

1) Enhanced Antenna Availability

- 4-MSPA for critical events where low-latency is important.
- OMSPA for routine science downlink.

2) Reduced Antenna Scheduling Coordination

- OMSPA occurs outside the scheduling system; depends only on being in the beam of a scheduled spacecraft.
- No scheduling contention with other missions during OMSPA.

3) Reduced Aperture Fees

- While NASA missions do not actually pay these fees, they do factor into a mission's bottom-line cost during the proposal phase.
- MSPA is currently offered at a reduced fee.
- While not yet decided, OMSPA would likely be offered at a reduced fee as well.

Key Question: OMSPA Applicability to EM-1-like Cubesat Deployments?

- We simulated an EM-1-like cubesat deployment scenario involving 10 cubesats in route to the moon.
- 3 DSN ground sites (Goldstone, Madrid, Canberra) and DSN affiliated MSU antenna.

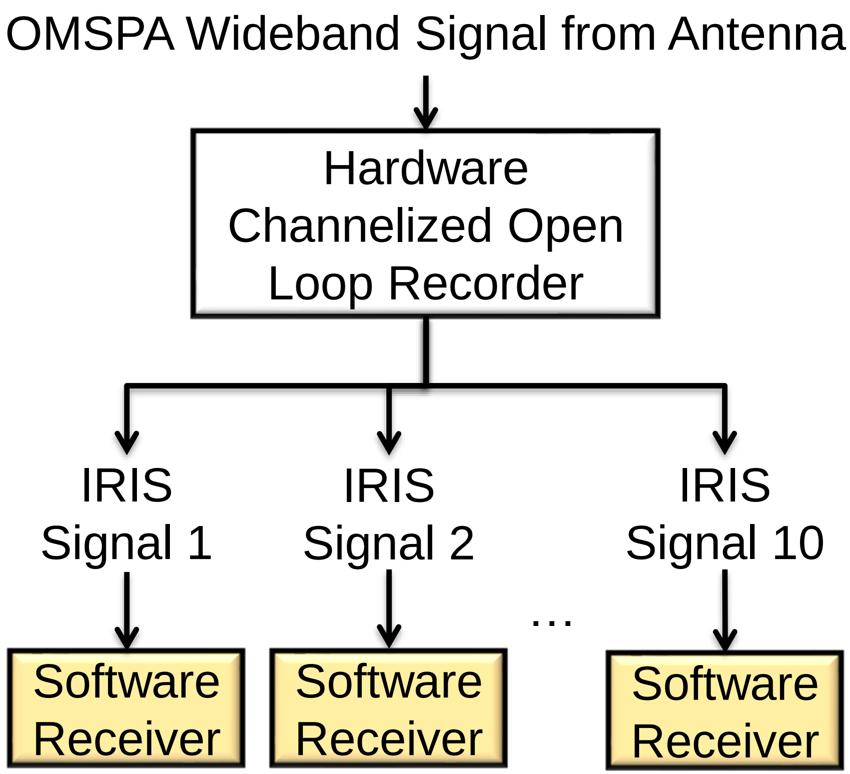
- A single cubesat was 'tracked' and was always 'in-beam' (in center of main beam).
- Other cubesats began in the main beam while following their own trajectory.
- Our scenario did not include any TCMs.
- Receive antenna was modeled as a 34m X-band antenna with 65dBi gain, while a 21m X-band antenna was modeled to have 60dBi gain.
- Each cubesat EIRP was assumed to be 10 dBW.
- Ground stations were assumed to have 33.5K noise temperature.

Simulating the Cubesat Waveforms

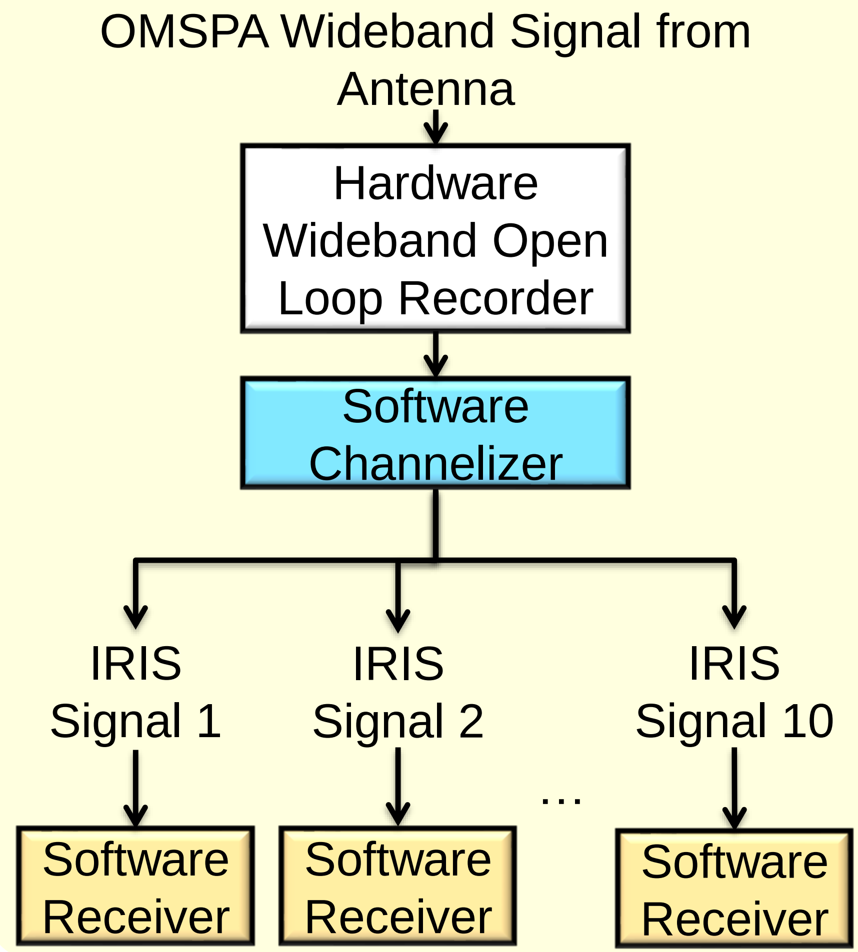
- An Iris MarCO waveform was recorded in lab:
  - 48 KSPS (8 kbps data throughput)
  - BPSK (Manchester/Bi-phase Coding)
  - Turbo 1/6 Code [includes cyclic-redundancy-check (CRC) block]
- This waveform was synthesized to generate 10 signals from different sections of the recording.
- The cubesats were assigned non-overlapping frequencies:
  - 8402.78, 8405, 8407, 8408, 8409.57, 8416.36, 8443.52, 8453, 8454, 8487 MHz. The Doppler shift from each cubesat's motion was also taken into account.
  - Synthesized signal covered 85 MHz.
- Received power at ground antenna a function of:
  - Free-space Path-loss
  - Antenna gain due to antenna pattern (60-65 dBi main-beam gain)
  - Cubesat EIRP (10 dBW)
- Simulation results are sampled once every 2 hours during the 96 hour trajectory. The ground site with largest elevation angle > 7 degrees is chosen at each simulation time instant.

Deciding the Receiver Architecture

Option 1: Channelized Recorder

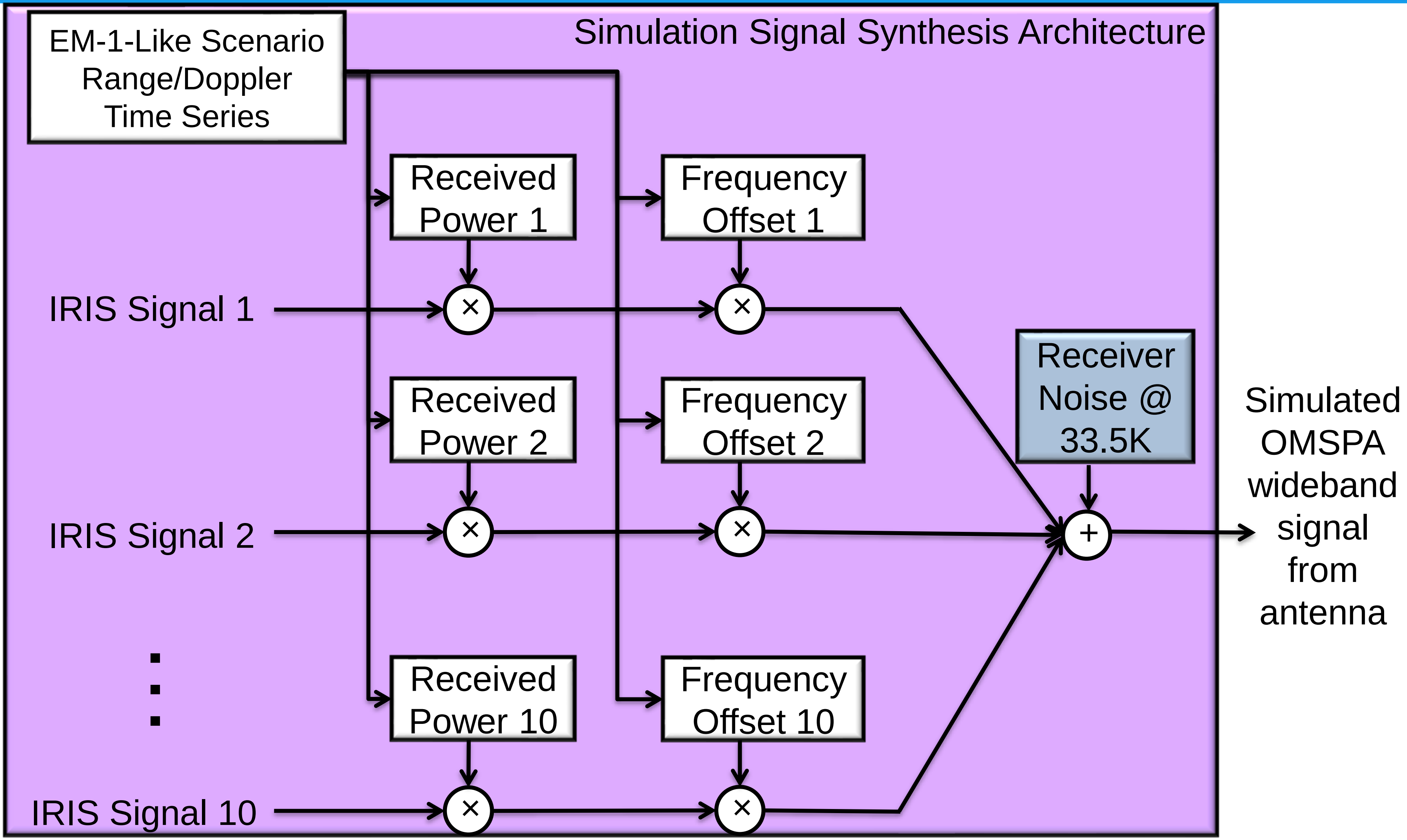


Option 2: Wideband Hardware Recorder

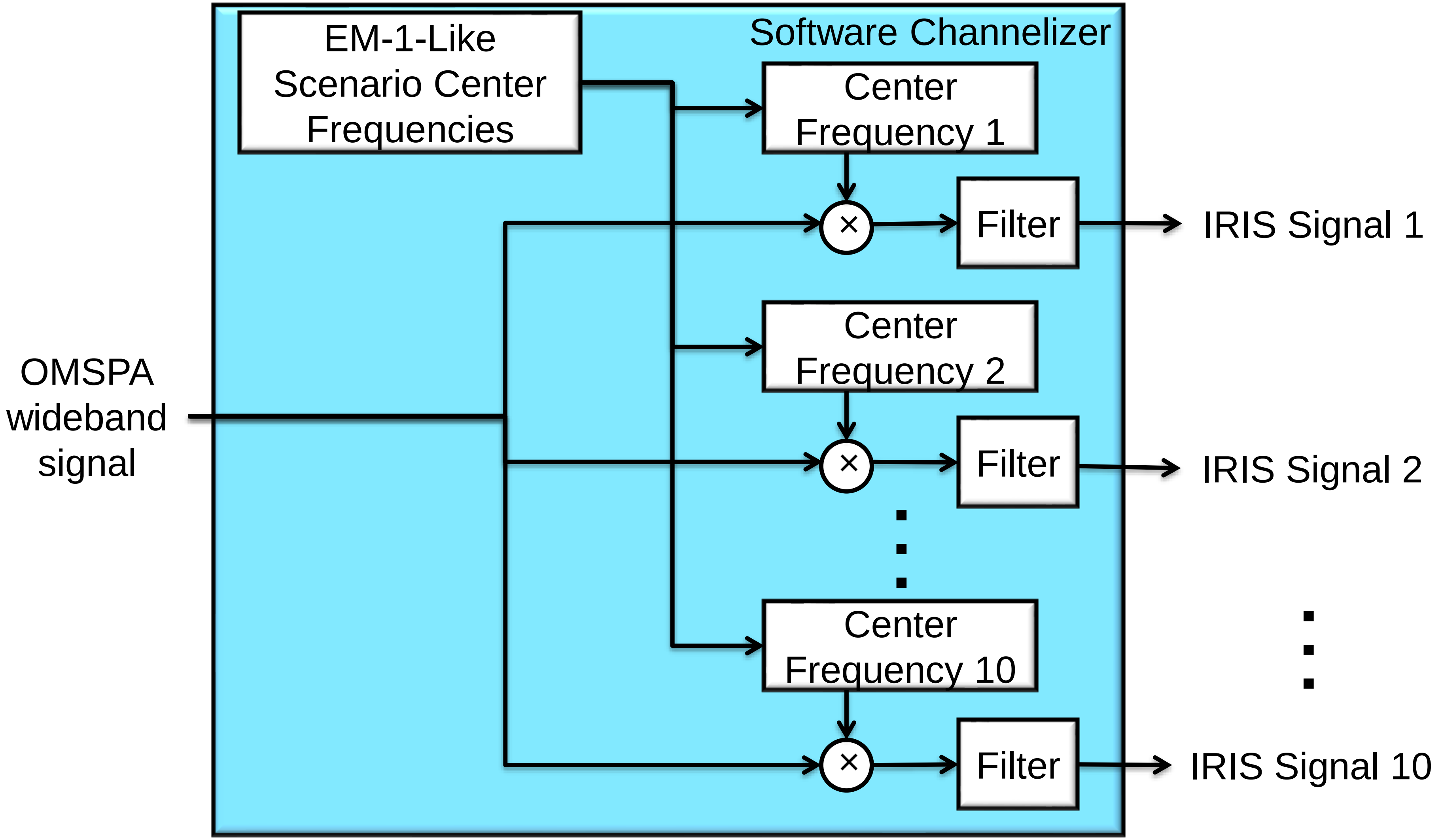


Option 2 was chosen for this simulation effort.

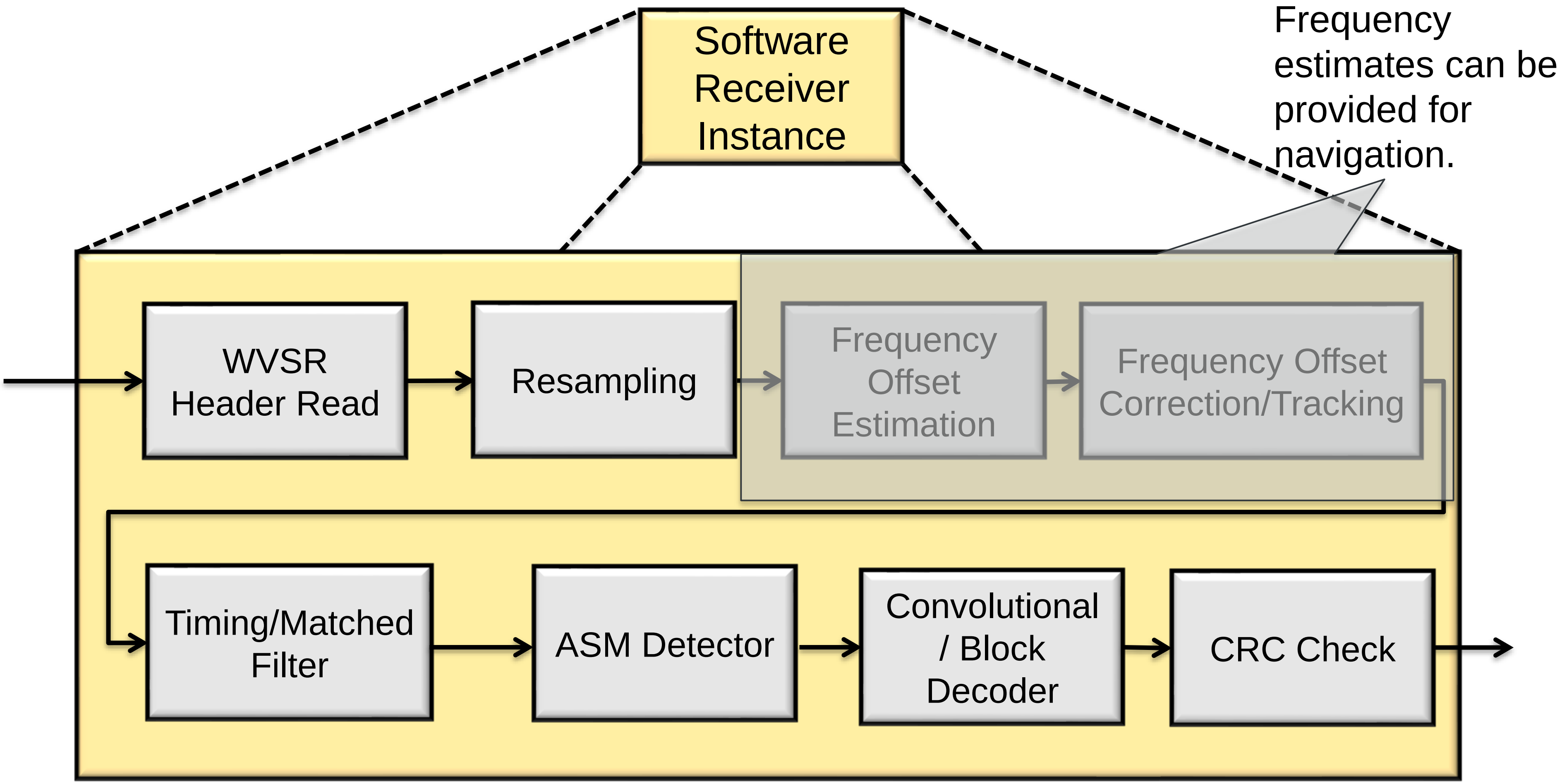
Synthesizing the Received Signal



Architecting the Software Channelization

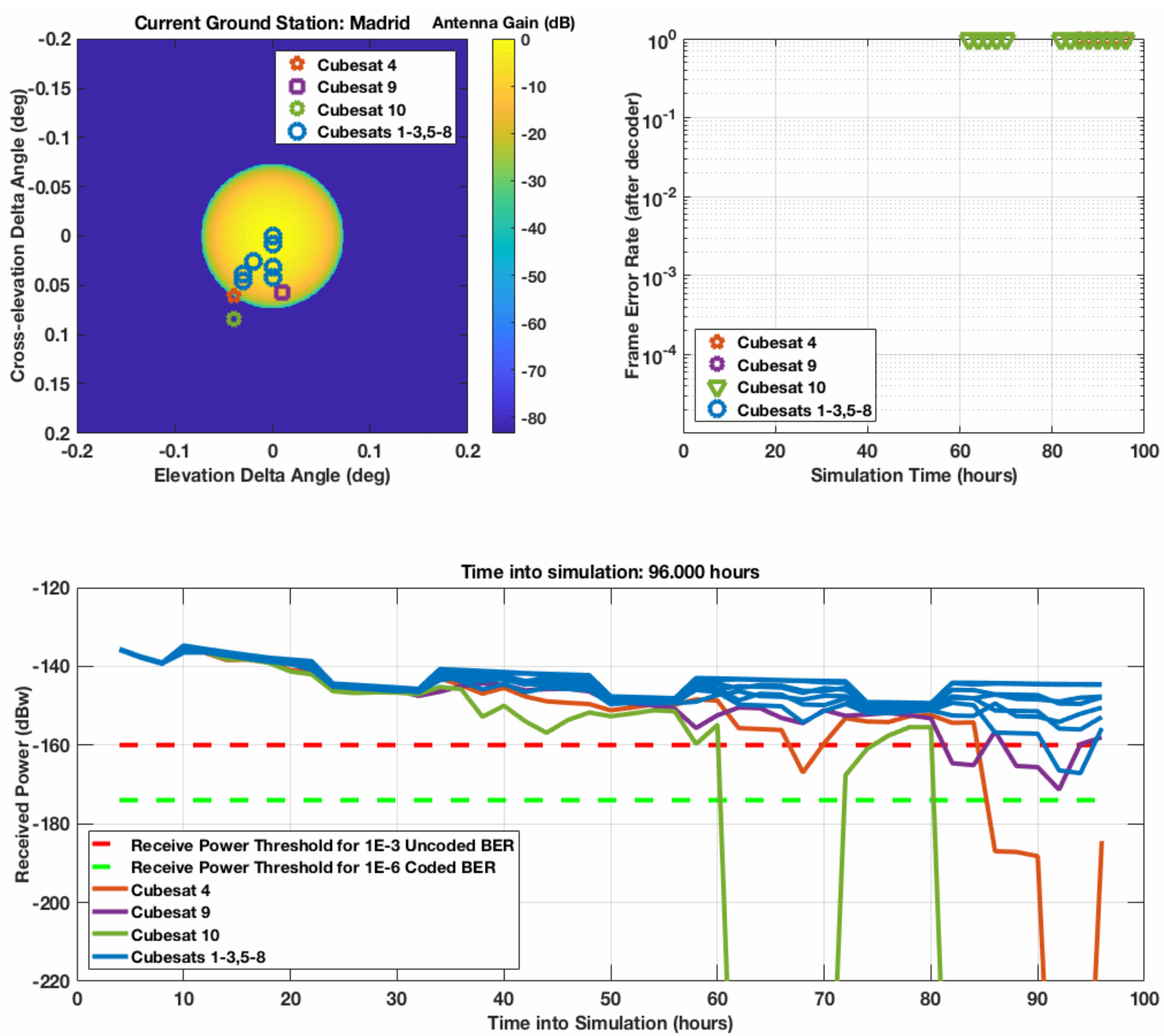


Architecting the Software Receiver



Note: Software Receiver Instances will vary in structure and underlying functions to suit the parameters of each particular spacecraft. **The software receiver for this IRIS waveform requires 8 seconds to process 10 seconds of raw data (1.25x faster than real-time).**

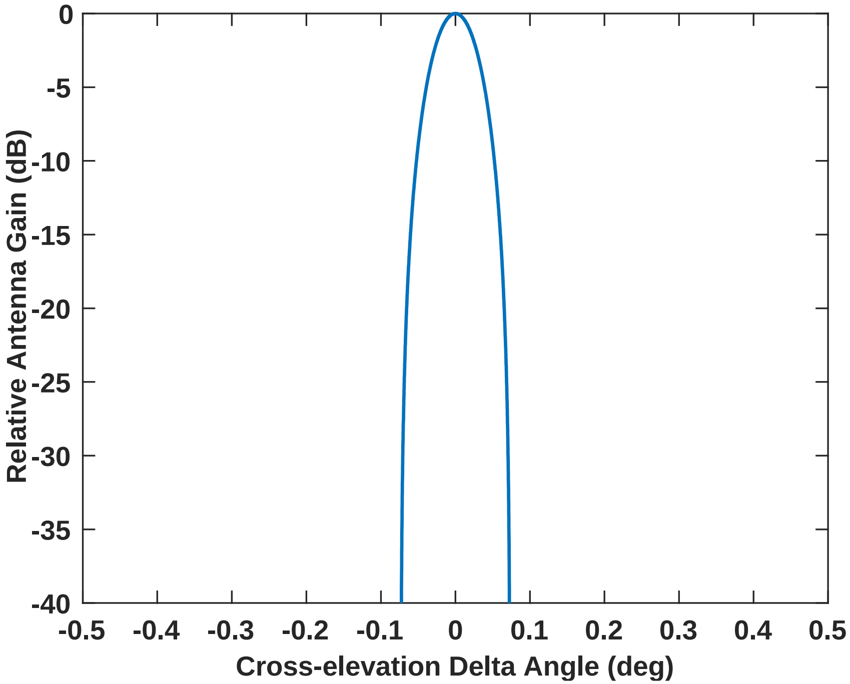
Simulation Results with Main Beam Only



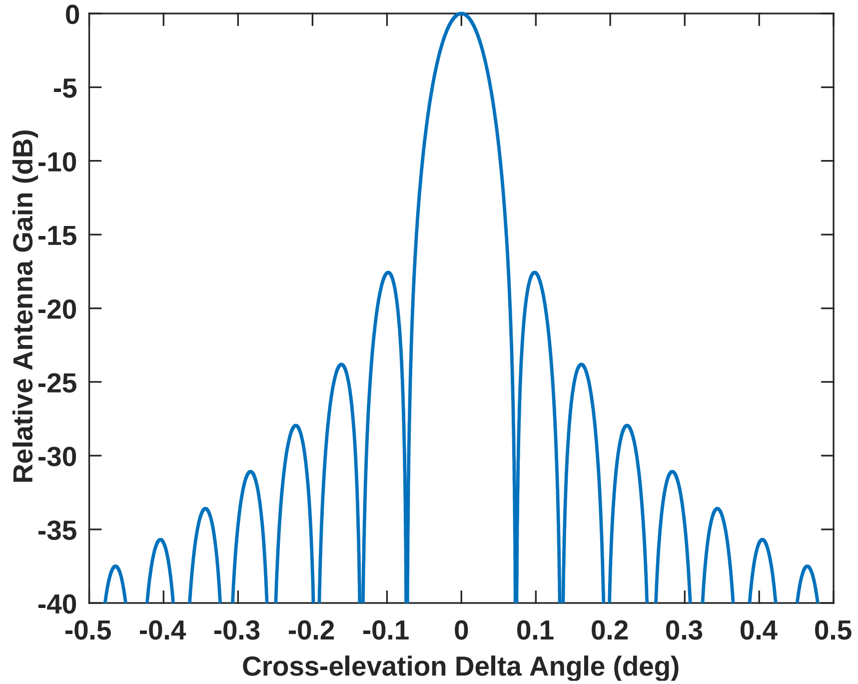
- Out of the 10 cubesats, 7 remained in main beam for duration of simulation.
- Frame errors only occurred once a cubesat completely exited beam.
- Even when cubesat 4 was slowly exiting beam at hours 65-71, frames were saved by the powerful Turbo 1/6 code.

Modeling Tracking in the Side-lobes

Main Beam Only



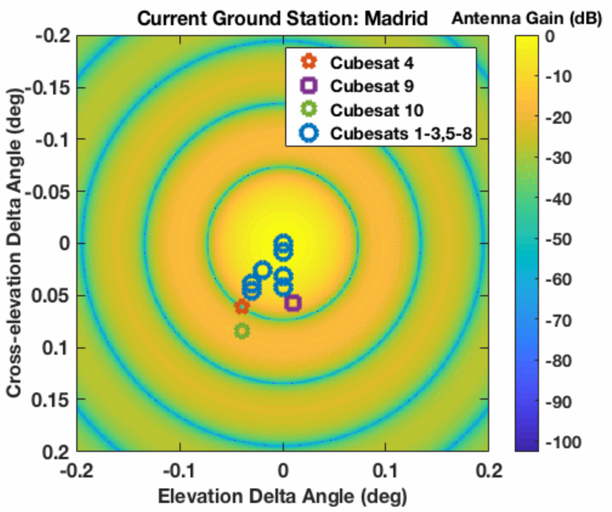
Main Beam with Side-lobes

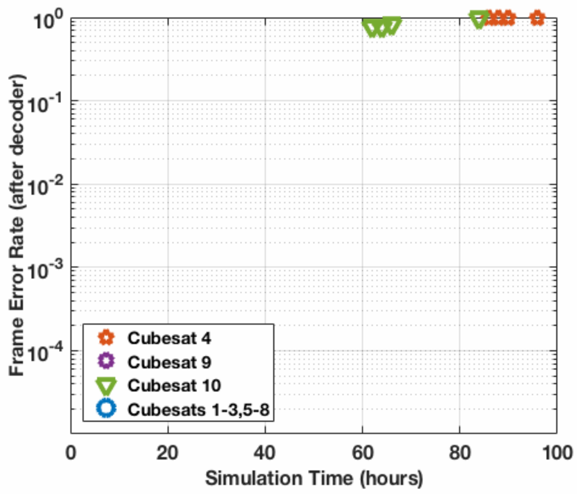


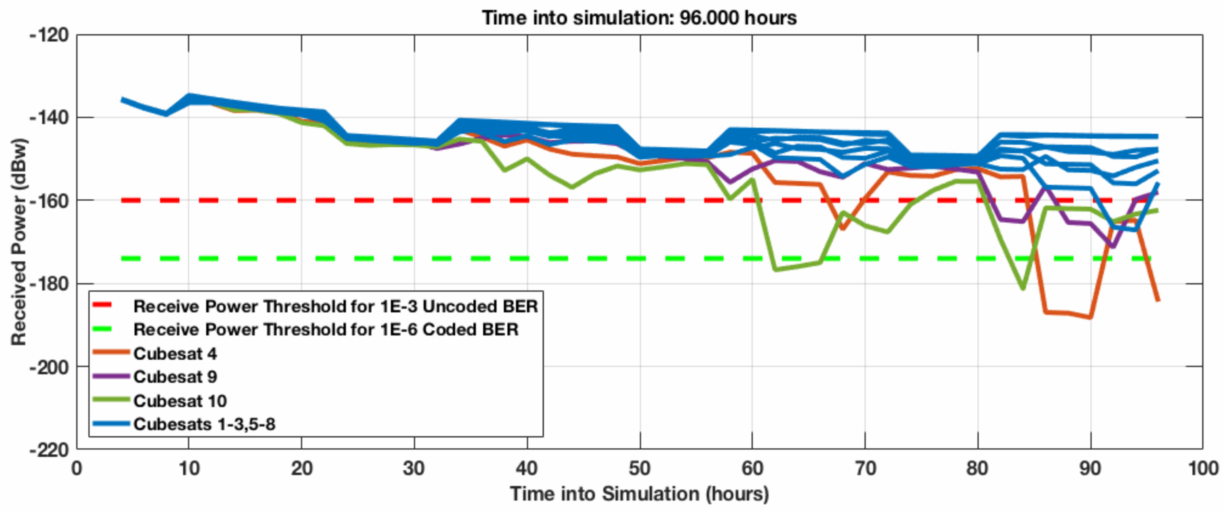
- The main beam is modeled as having a width of ~1/10 degree.*
- Outside of the main beam, the first side-lobe is still relatively strong at only 20dB loss.
- Phase flips may occur at side-lobes, but the software receiver can be made to cope.
- Nulls are relatively narrow, and thus receiving cubesats through side-lobes is promising.

* Antenna pattern specification obtained from David D. Morabito <david.d.morabito@jpl.nasa.gov> and David P. Rochblatt (333F) <david.j.rochblatt@jpl.nasa.gov>

Simulation Results with Main Beam and Side-lobes

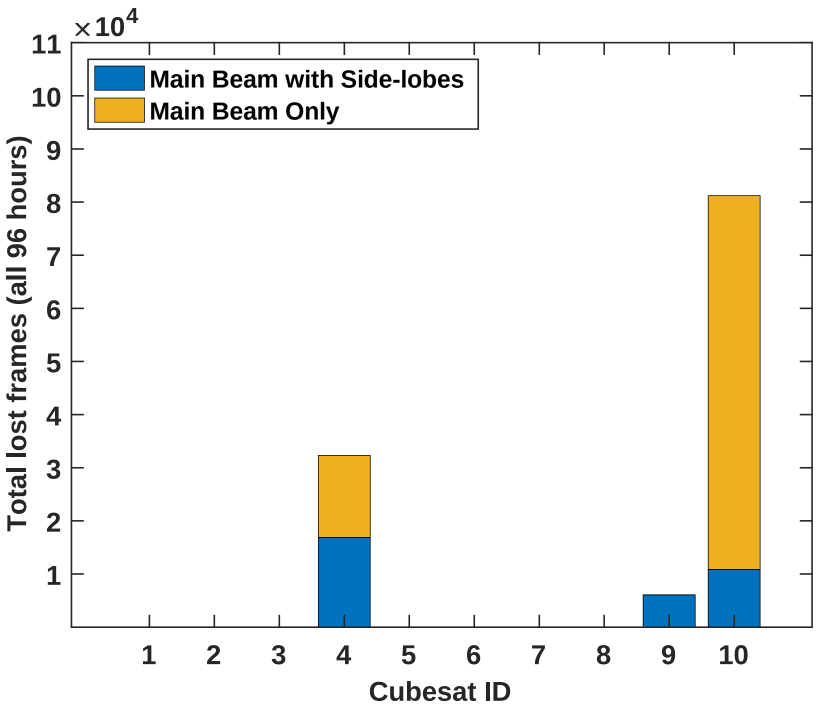






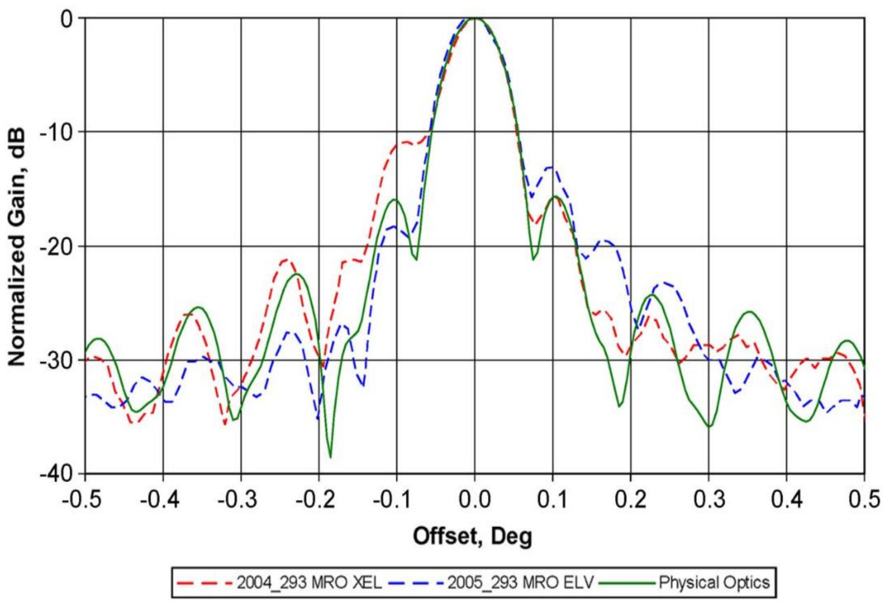
- In 96 hours, cubesat 10 traveled furthest to the first side-lobe, which yielded about 17dB antenna gain loss.
- Frame errors would occur when a cubesat is in very close to a null.

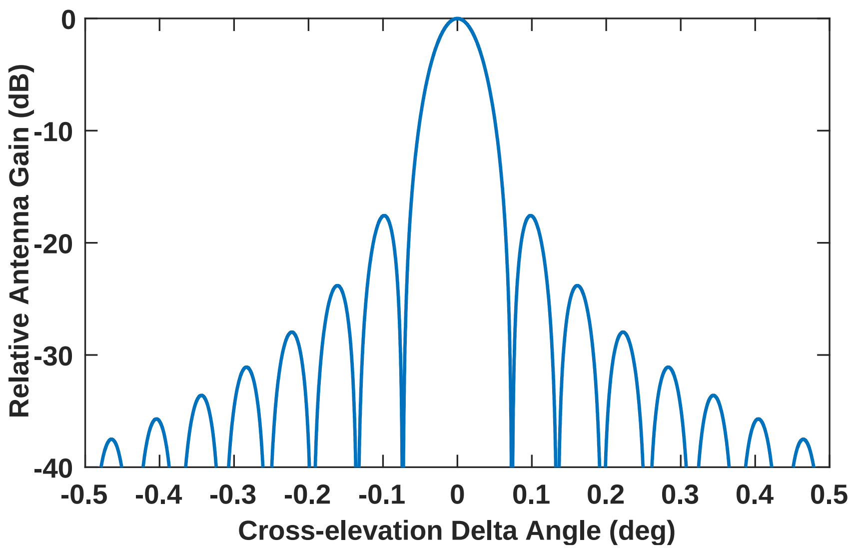
Benefit of Side-Lobe Reception



- Cubesats 4 and 10 achieved approximately 40% and 87% reduction in dropped frames, respectively, due to the use of the first side-lobe for receiving of the data.
- Cubesats 4, 9, and 10 lost less than 4% of their total transmitted frames for the duration of the 96 hour simulation when side-lobes were utilized. Other cubesats did not drop frames.
- The benefit of the use of side-lobes can also be realized by traditional DSN MSPA mode.

Nulls in Practice





- In practice, nulls are not infinitely deep.
- < 40dB attenuation up to +/- 0.5 degree offset. For near earth or lunar scenarios, this may be acceptable with powerful coding.

D. D. Morabito, W. Imbriale and S. Keihm, "Observing the Moon at Microwave Frequencies Using a Large-Diameter Deep Space Network Antenna,"in *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 3, pp. 650-660, March 2008.

Summary & Conclusion

- Opportunistic MSPA applied to an EM-1-like deployment scenario was simulated using a lab-collected Iris waveform.

- Antenna patterns, range, and antenna gain were incorporated to model received powers from different cubesats from the different ground stations (Goldstone, Canberra, Madrid, and MSU).

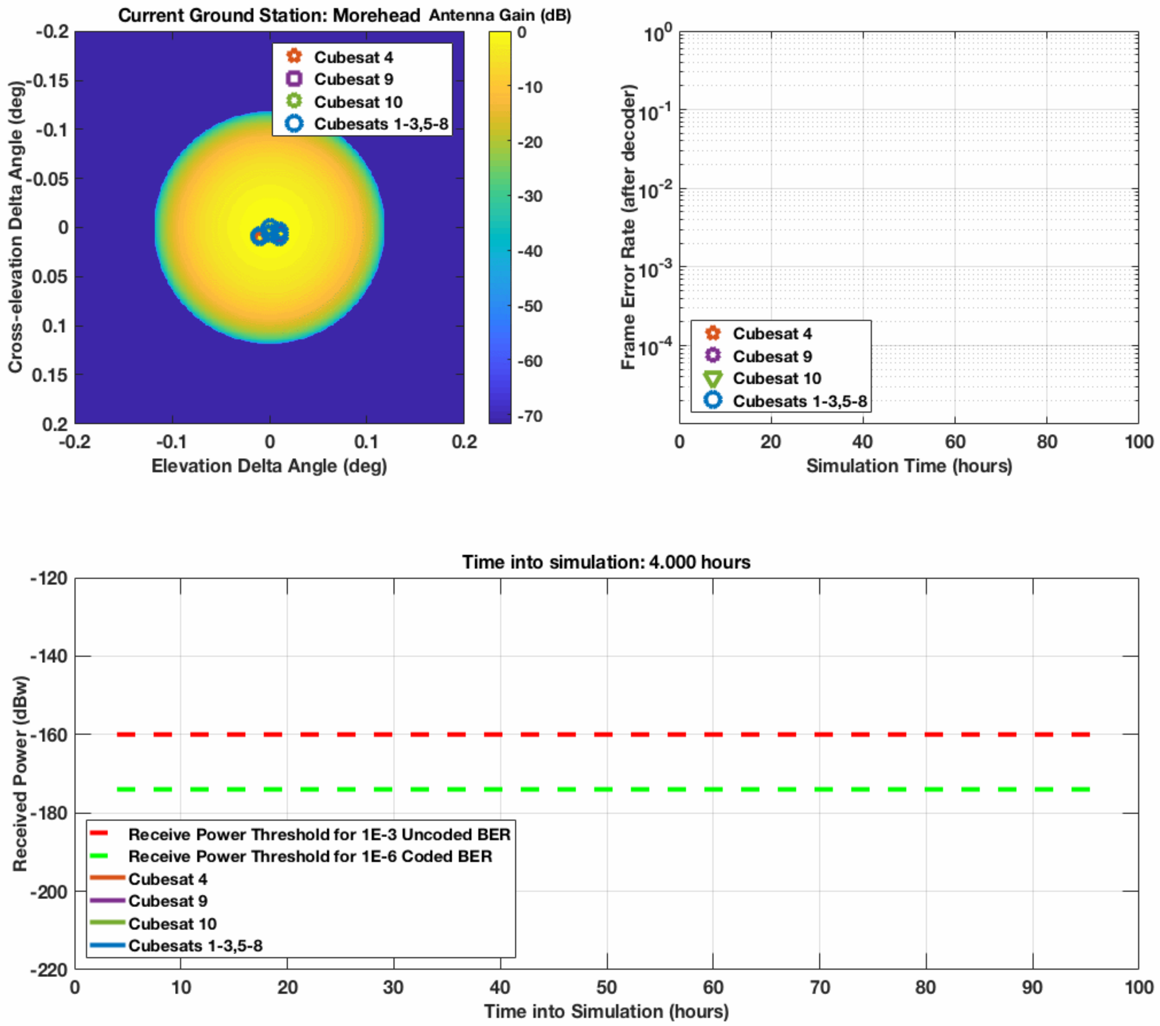
- Over the first 96 hours of EM-1 scenario, <u>with</u> <u>no</u> <u>TCMs</u>, 7 of 10 cubesats were successfully demodulated over the scenario time samples. 3 of 10 cubesats experienced frame losses due to moving outside the main beam, not due to path-loss.

- Less than 4% of the total frames are lost when only the main lobe is utilized for the simulation duration. This is reduced to 1% of the total frames when side lobes are utilized for the 96 hour simulation duration.
  - Outages tend to be brief as they only occur when a cubesat is very close to a null.

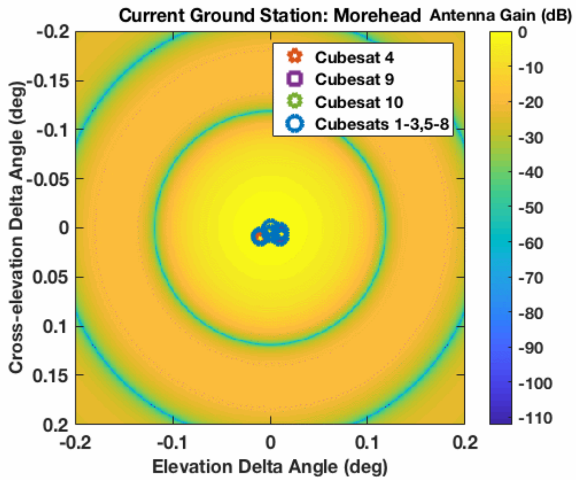
<u>Conclusion</u>: OMSPA can be successfully applied to EM-1-like scenarios for downlink telemetry capture for the initial deployment period.

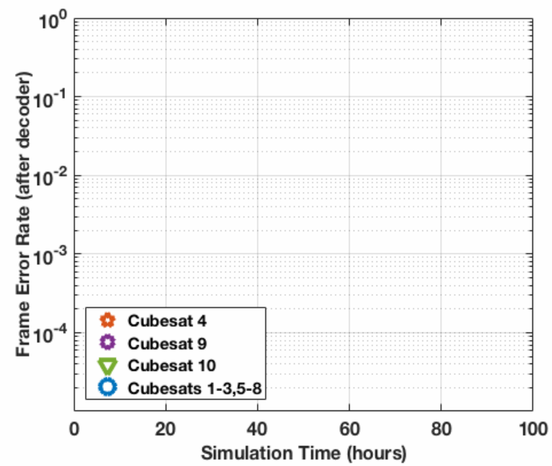
Thank You!

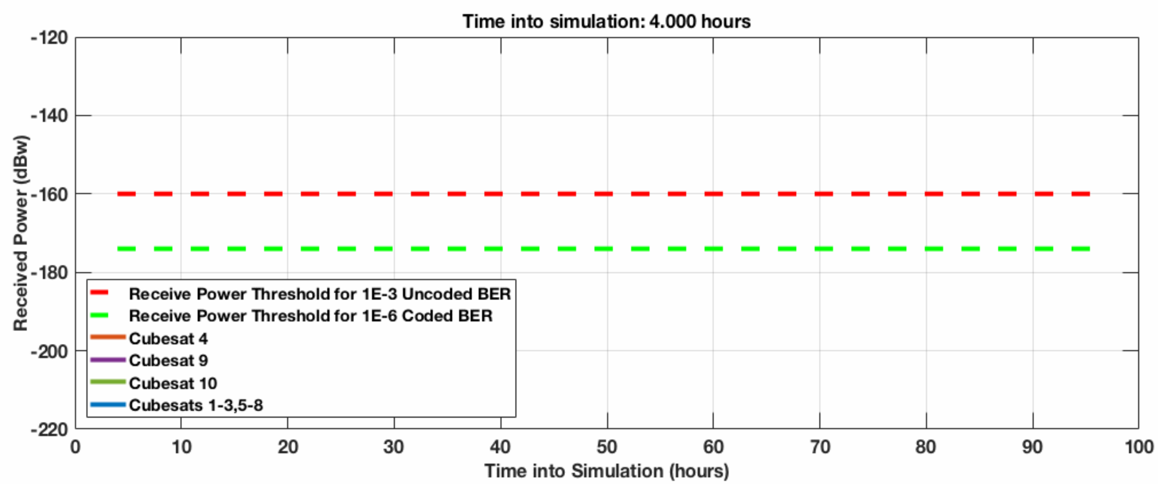
BACKUP: Animation without Sidelobes (2 hour sample interval)



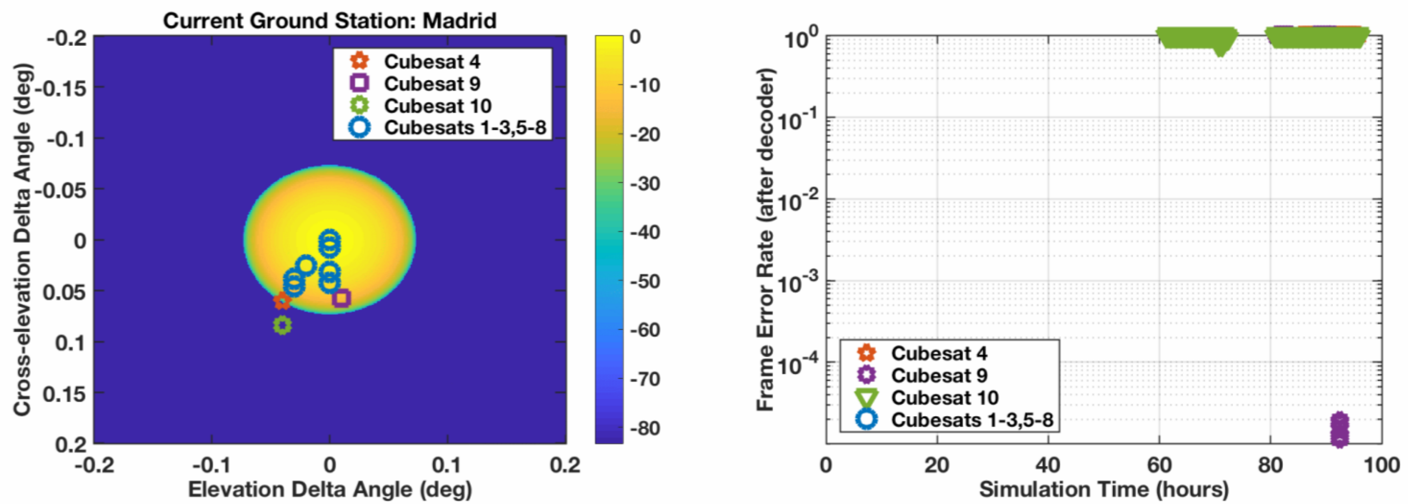
BACKUP: Animation with Sidelobes (2 hour sample interval)

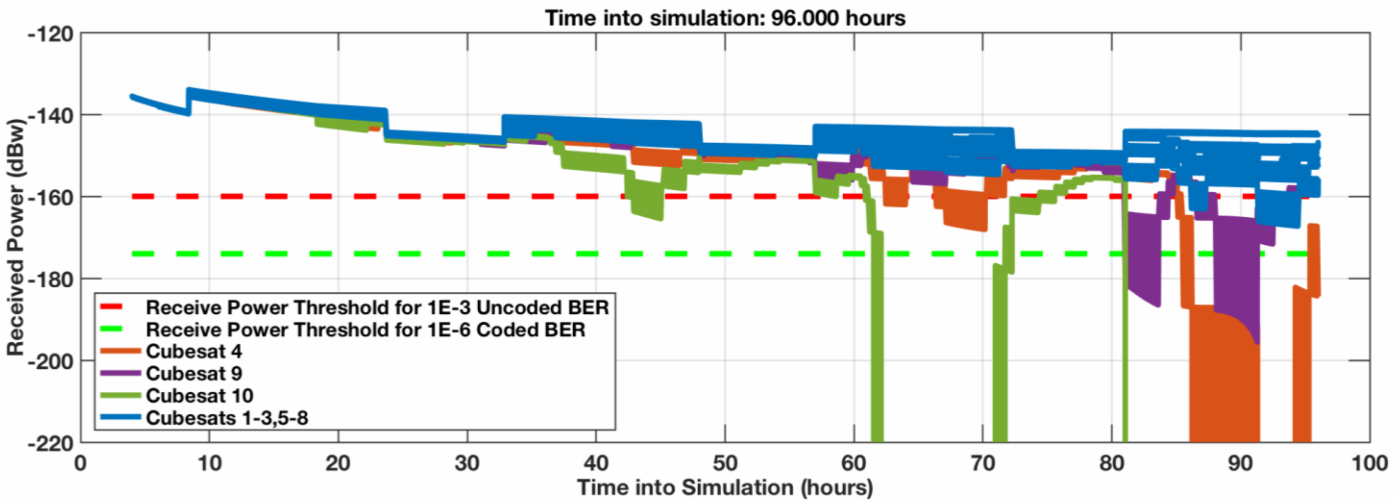




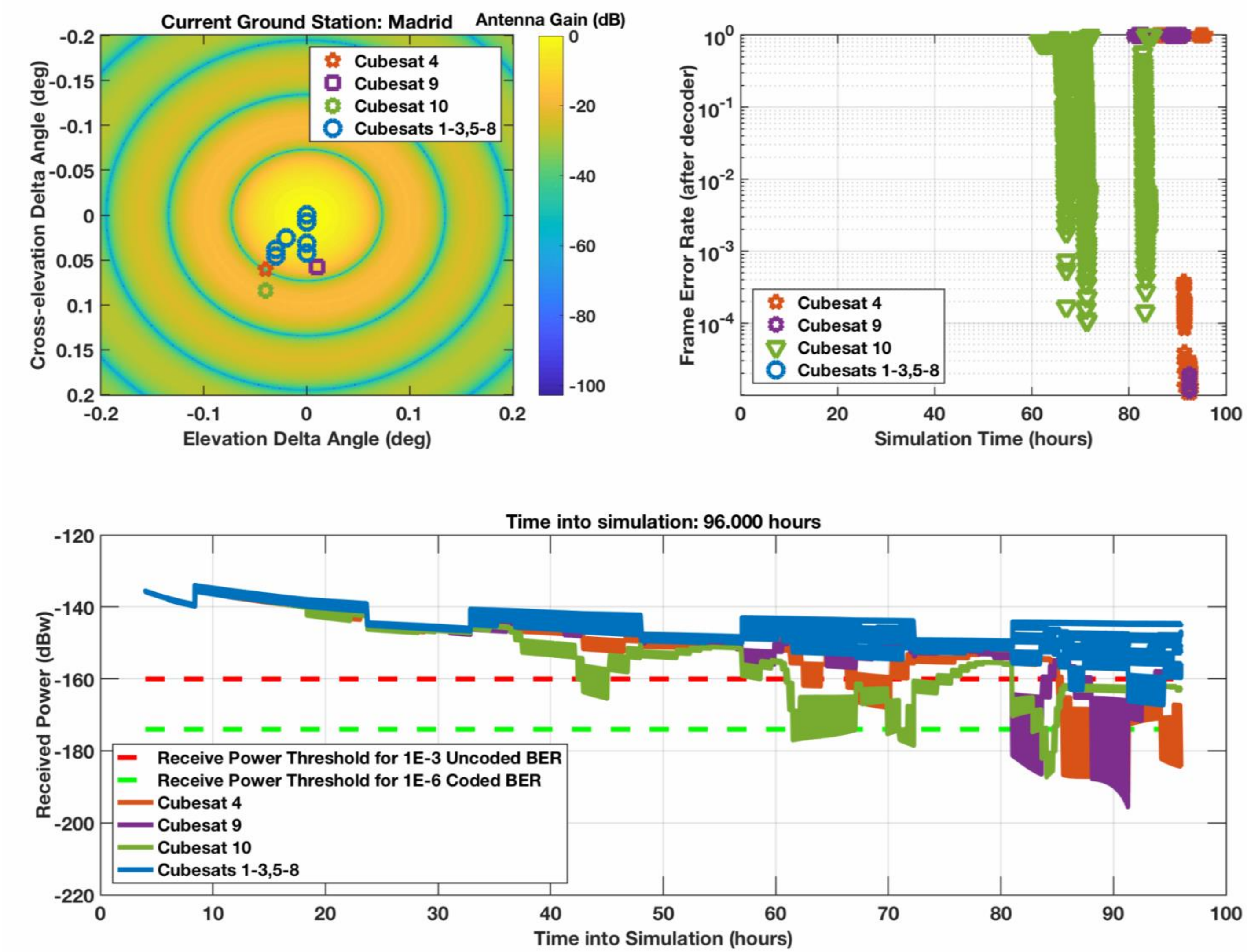


BACKUP: Finely Sampled Simulation with Main Beam Only

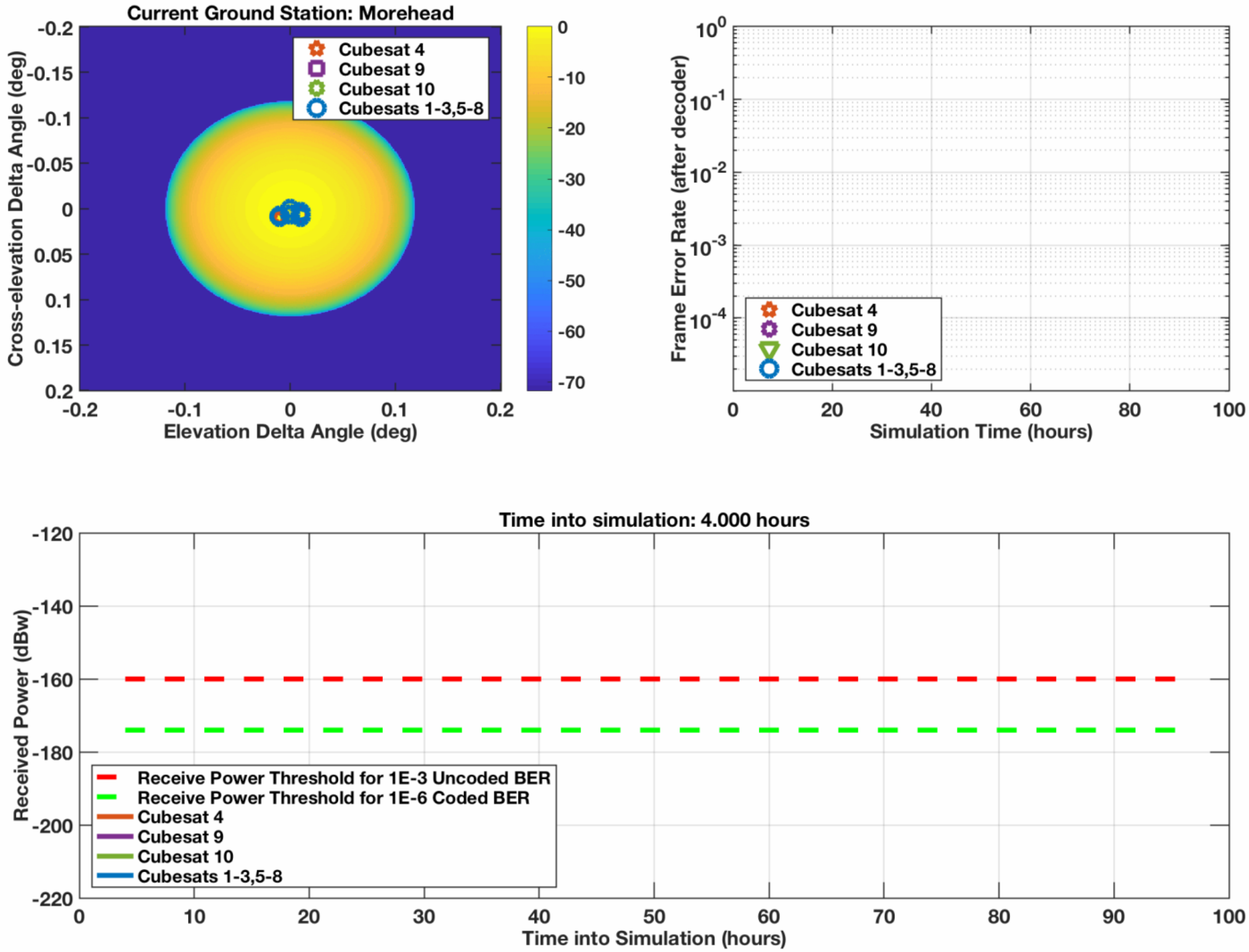




BACKUP: Finely Sampled Simulation with Sidelobes



BACKUP: Animation without Sidelobes (Finely sampled through interpolation)



BACKUP: Animation with Sidelobes (Finely sampled through interpolation)